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ENVIRONMENTAL ANALYSIS RESEARCH

EVALUATION OF WATER YIELD POTENTIAL IN EAST PUTAH CREEK WATERSHED UNDER MULTIPLE USE MANAGEMENT

August 1973

PROFESSOR ROBERT H. BURGY
Principal Investigator

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Davis

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The U.S.D.I. Bureau of Land Management and Bureau of Reclamation personnel who have supported, encouraged and expedited the accomplishment of these research studies are sincerely appreciated.

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SUMMARY AND PRELIMINARY CONCLUSIONS

Progress in research on the watershed lands of the East Putah Creek Study Area covered herein for the 1972-73 fiscal year has identified these significant points:

-The hydrologic responses of the gaged tributaries form the basis for testing the predicted change in magnitude of runoff as influenced by vegetative density and composition. The predicted yield increase estimate continues to appear significant.

-The results of completed studies currently indicate the possibility for application of these analytical procedures to other basins for assessment of management alternatives.

-Analysis of methods for integration of a broad array of information into a compatible plan for this area is progressing.

-Potential environmental impacts of vegetative conversion have been delineated.

-Diagnosis of nutrient deficient areas by aerial photograph interpretation shows promise for use in this watershed study.

-Preliminary cost estimates for conversion have been developed.

-Biological sensitivity indices are being prepared which will aid in predicting impacts of management alternatives on aquatic systems.

INTRODUCTION

Investigation of the management potential of public lands administered by the U. S. Bureau of Land Management in a parcel lying upstream from Lake Berryessa in Napa and Lake Counties was initiated in 1969. At the outset the objective of the studies was centered in evaluating the possible augmentation of runoff waters through the management and control of water losses produced by indigenous watershed vegetation.

To facilitate this evaluation, extensive efforts were devoted to the development of an adequate information base and inventory of essential watershed characteristics. New data on hydrologic characteristics of the region were acquired and deficiencies in basic data and knowledge of the region were identified. Succeeding phases of the study have directed efforts toward supplemental studies to meet the informational needs for a comprehensive watershed planning activity. The complex interrelationships among the several kinds of watershed lands, diverse ownerships and the many multiple purpose uses inherent in the region demand intensive study to permit development of effective, responsive programs for the area.

A high priority segment of the study deals with ecological relationships and environmental effects associated with land use and management studies. Both the terrestrial and the aquatic components of the area have been added. Field and laboratory research on special characteristics of the basin are included for problem soil sites and to quantify agronomic requirements.

The preliminary estimates of the water yield potential for this region through vegetation control programs has been assessed annually by a comparative analysis of data from sites of quantified yields. Over a wide range of annual rainfall experience, now including an extremely deficient year of about 12+ inches, the annual runoff comparisons continue to confirm the yield potential. It must be noted that all estimates and evaluations are based on data reported to the

project in "preliminary form" and are therefore subject to revision and modification.

This Annual Report may be best considered as an "Interim Report", meeting the schedule specified by contract. The time schedule of hydrologic studies, however, is not directly amenable to a fiscal calandar, and hydrologic evaluations should be based on complete "water year" summaries. Due to the lag time for data acquisition, processing and distribution, this information will become available in late fall. Updated analysis to be prepared for the annual February Progress Meeting is expected to provide substantial augmentation.

Using the format of previous reports, three sections are included herein:

Section I presents the format and discussion of the watershed planning procedure for the East Putah Creek Watershed. Incorporated are alternatives of management, ecological factors, environmental considerations and other factors vital to the selection of optimum planning alternatives.

Section II outlines progress during 1972-73 in the agronomic studies conducted by Dr. M. B. Jones of the U. C. Davis Department of Agronomy and Range Science.

Section III, prepared by Dr. A. W. Knight and Mr. C. A. Seigfried, presents the progress report on hydrobiological studies. These results are providing new data on the biological composition and the relative sensitivity of the streams and aquatic organisms to watershed uses upstream.

Planned ongoing research thrusts are noted within each discussion. The overall objective of defining a comprehensive multiple-use management plan and program for the East Putah Creek Watershed, meeting needs and desires of all parties, is in process and preliminary planning details for a pilot program on a selected site on the East Putah Creek Watershed are currently under development.

SECTION I

WATERSHED PLANNING AND ANALYSIS

Kenneth L. Gray

Robert H. Burgy

WATERSHED PLANNING AND ANALYSIS ON EAST PUTAH CREEK WATERSHED

KENNETH L. GRAY AND ROBERT H. BURGY

INTRODUCTION

Since 1969, the University of California, Davis, Department of Water Science and Engineering has been studying the concept of vegetative conversion for water yield augmentation on the East Putah Creek Watershed. Resources have been inventoried, predictive models developed, and special studies undertaken with the hope of gaining sufficient information to accurately predict the watershed's response to conversion. From this work, two tentative conclusions can be drawn:

1) Conversion from deeprooted woody species to annual grasses and forbes will result in significant water yield increases.
2) Serpentine soils can support good grass stands under conditions of proper soil amendments and soil preparation. Further work will be needed to devise a system for determining amendment requirements for particular locations.

The task now underway is to consider these conclusions along with the supporting information to form a workable plan. An objective of the plan would be improvement of water yields while at the same time either enhancing or at least maintaining the watershed for other uses. This goal is consistent with the multiple watershed-use concept. Successful accomplishment of this objective requires the steps outlined in Fig. 1. (Sections of the text discuss each step in the process).

I. Data Collection

The watershed data base reported in the July 1970 report included soils, vegetation, geology, water quality, wildlife, etc. inventoried for the East Putah Creek Watershed. As a result of the initial

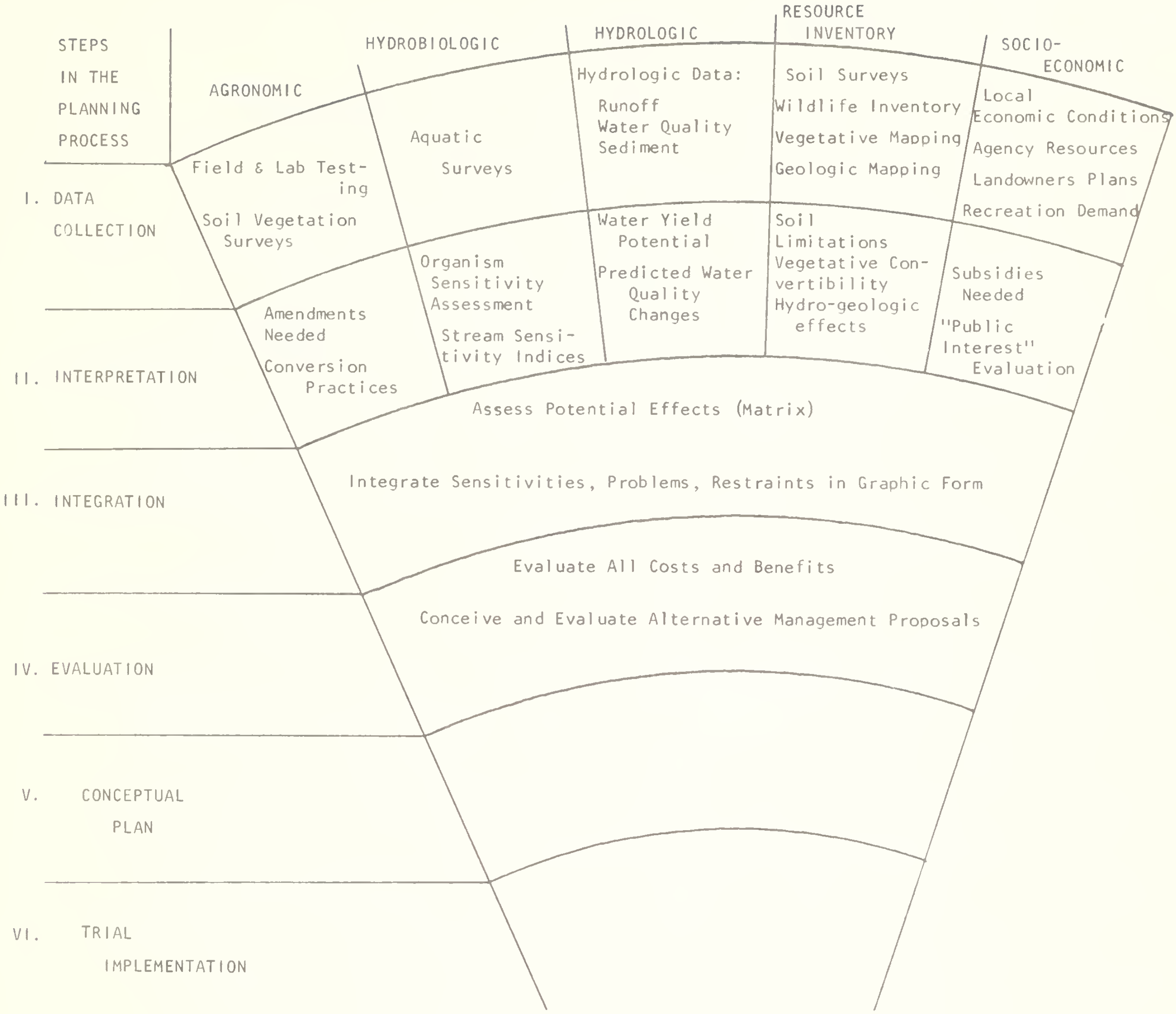


FIGURE 1. STEPS IN THE PLANNING PROCESS FOR EAST PUTAH CREEK WATERSHED.

investigations, it was decided that some necessary data was not available. The current agronomic and hydrobiologic studies were undertaken to fulfill that need. Data collection in these two subjects is continuing. In addition, hydrologic data continues to be collected for analysis.

II. Interpretation

HYDROLOGY

Water Yield Potential for the East Putah Creek Watershed was estimated early in the study. Later work has confirmed the estimate.

HYDROBIOLOGIC

Artificial streams in the laboratory have been set-up in an attempt to develop relationships between sediment levels and survival of key benthic species. If successful, it will be possible to assess the potential losses in aquatic life due to sedimentation rate increases by assessing the abundance and/or existence of a few benthic organisms.

AGRONOMIC

Experiments have shown that good grass stands can be established on serpentine soils. Work is now underway to determine a method of assessing polypedons with respect to specific amendment requirements. When completed, it should be possible to accurately predict amendments needed for a given site so that only those nutrients needed are applied.

RESOURCE INVENTORY

Soil interpretations have been made by the Soil Conservation Service for soil series identified with the East Putah Creek Watershed. Soil suitabilities for erosion potential, fertility, septic tank suitabilities and many other uses have been made or can easily be estimated.

The vegetative maps presented in the data collection phase were interpreted for vegetative convertibility. Lands where the woody vegetation covered 50% of the land are considered suitable for conversion.

investigations, it was decided that some necessary data [illegible] the current agronomic and hydrobiologic studies were [illegible] to fulfill that need. Data collection in those two subjects [illegible] In addition, hydrologic data continues to be collected [illegible]

[illegible] Data Interpretation

HYDROLOGY

Water [illegible] Formulation [illegible] the East [illegible] [illegible] water [illegible]

HYDROBIOLOGY

[illegible] streams in the [illegible] [illegible] relationships between [illegible] [illegible] [illegible]

SOILS

[illegible]

III. Integration

This step in the process attempts to synthesize the fields of study into information useful to planners and decisionmakers. The information contained herein includes:

A. A written description of the potential impacts of vegetative conversion.

B. A map of the East Putah Creek Watershed which integrates the restraints to vegetative conversion.

A. Impacts of Vegetative Conversion

Much of the earlier work completed by the Department of Water Science and Engineering on the East Putah Creek Watershed has been preparatory for the evaluation of Environmental Impacts. Surveys of soils, vegetation, topography, wildlife, aquatic life, agronomy and hydrology have all contributed essential information. The tables titled "Tentative Relationships of Watershed Management to Representative Environmental Planning Problems" which were included in the August 1972 report attempted to synthesize this information and deal with the overall problem of the environmental impacts of vegetative conversion. This section summarizes more extensive work completed during the current year to make an assessment of the environmental impact of vegetative conversion on the East Putah Creek Watershed. This is a general assessment of potential and/or possible effects. When designing a project, this assessment should be valuable in determining necessary mitigation measures.

The discussions of impacts are presented in four sections as follows:

1) On-Site - Short Term
2) Off-Site - Short Term
3) On-Site - Long Term
4) Off-Site - Long Term

To facilitate understanding of the terms a list of definition is included.

DEFINITION OF TERMS

1. On-Site: This term means on the site actually being converted. It does not include any stream channels.
2. Off-Stie: This is all the area affected except the actual converted watershed. For our purpose we limit off-site discussions to the general area of the East Putah Creek Watershed and Lake Berryessa.
3. Short-Term: This is a time constraint and includes the time when conversion is actually taking place plus the first growing season thereafter.
4. Long-Term: This includes the long-term impact for the anticipated life of the project.
5. Impact Chains: A series of impacts, each induced by a previous impact. For example: a parking lot is built which reduces infiltration, which increases runoff, which increases erosion, which increases turbidity, which reduces light penetrations in a stream, which reduces primary porductivity, which reduces food supply of game fish, which diminishes a given fisherman's recreation experience. The lost fishing potential is the end product of an impact chain which began with the construction of a parking lot.
6. Cumulative Impacts: Many small impacts become additive to form a greater impact. In the example of the impact chain, the cumulative effect of many parking lots would decrease fishing potential, whereas one lot might have no significant affect.
7. Direct and Indirect Impacts: In a project such as vegetative conversion on the East Putah Creek Watershed, a direct impact would be the loss of woody vegetation while an indirect impact would be water quality changes in Lake Berryessa.

IMPACTS

Section 1: On-Site - Short Term

Soil

The absence of ground cover after the woody vegetation is removed and before a good stand of grass is established has the potential of creating severe erosion problems. The degree of this impact will depend on the timing of conversion and the date and intensity of the first winter rains. If a grass stand is established before the first major storm of the season, erosion problems will be minimal. If heavy rains occur early, the soil surface could be eroded along with much of the grass seed and soil amendments applied.

The physical disturbance of the soil surface during the conversion is another impact. This disturbance will increase "soil susceptibility" to erosion.

Wildlife

The noise, dust, fire and physical activity associated with the conversion process will have detrimental effects on wildlife. Large mammals such as deer should not be greatly affected due to their mobility but smaller animals such as mice, gophers, snakes, etc. might be killed or have their habitat destroyed by the conversion process. These impacts are temporary and will be mitigated with time.

Recreation and Grazing

In addition, the noise, dust, fire and smoke during the process of conversion would have temporary detrimental effects on recreation and livestock grazing. During the first year, the newly seeded hillsides will be in a delicate condition. It may be advisable to prohibit public and commercial use of the land during this period. If so, this loss of use must be considered a detrimental effect.

IMPACTS

Section 2: Off-Site - Short Term

Hydrology

If, as described in the previous section, heavy rains come during the conversion process, large amounts of sediment will enter the streams. The turbid water will have detrimental effects on aquatic life in the stream as well as downstream in Lake Berryessa. Deposition of the sediment in the streams could reduce the flow capacity of the stream and make flooding more likely during future storms.

Vegetation

Streamside vegetation could be covered or destroyed by deposited sediment in the stream. After the stream recedes, the new sediments could provide a good media for plant growth.

Aquatic Life

Large amounts of sediment entering streams in the East Putah Creek Watershed could have extremely detrimental effects on aquatic life in the streams and in Lake Berryessa. In the streams, sediment could cover the rocky substrate to form a smooth surface which greatly decreases potential habitat for benthic organisms. High turbidity in stream and lake waters may have direct lethal effects on many aquatic organisms, including game fish. The large amounts of nutrients accompanying highly turbid water could provide the materials for algal blooms in the streams and the lake. The added nutrients would speed the eutrophication process in Lake Berryessa. The suspended sediment would also reduce light penetration which could limit the primary productivity of the aquatic system.

Recreation

Swimming and boating would be directly affected by increased turbidity. Since large inflows of sediment are associated with winter

storm events, when recreation use is low, this impact would be minimal.

A more significant impact on recreation would be the secondary effect of the disruption of the present aquatic life systems. If turbidity results in a fish kill, the fishing potential will be reduced; if Lake Berryessa becomes eutrophic, many recreation uses will suffer.

IMPACTS

Section 3: On-Site - Long Term

Hydrology

The major purpose of vegetation conversion is for increased water yield. If the streams and channels which are to carry the increased flows are not capable of handling the water then extremely detrimental impacts result. This has been demonstrated in University of California research at the Hopland Field Station where 100% of the woody vegetation on an experimental watershed was removed. The resulting water flows scoured the streams to the point where major slips began to occur. The process is outlined in Fig. 2. A carefully planned conversion of the East Putah Creek Watershed would not necessarily produce the same results. There is evidence of naturally occurring land slips associated with the stream channels on-site and since increased water flow is known to accelerate the process at least some increase in slip activity should be considered.

Some studies have also shown that when water yield increases, there is a proportional increase in nutrient output. Other experiments indicate that little increase is experienced since the increase in water yield tends to dilute the nutrients. Which hypothesis will be validated by the East Putah Creek Watershed is unknown. The parameters which relate water yield-water quality effects have not been quantified on this site. Moreover recent data from similar sites is becoming available to aid in evaluating the effect.

Longer duration of flows will be a beneficial effect of conversion. In nearly all cases water flow during the summer will enhance use of the area.

Microclimate

An established grass cover releases almost no water vapor to the atmosphere during the summer while a brush-tree cover continues to transpire. The decreased evapotranspiration may decrease the relative

IMPACTS

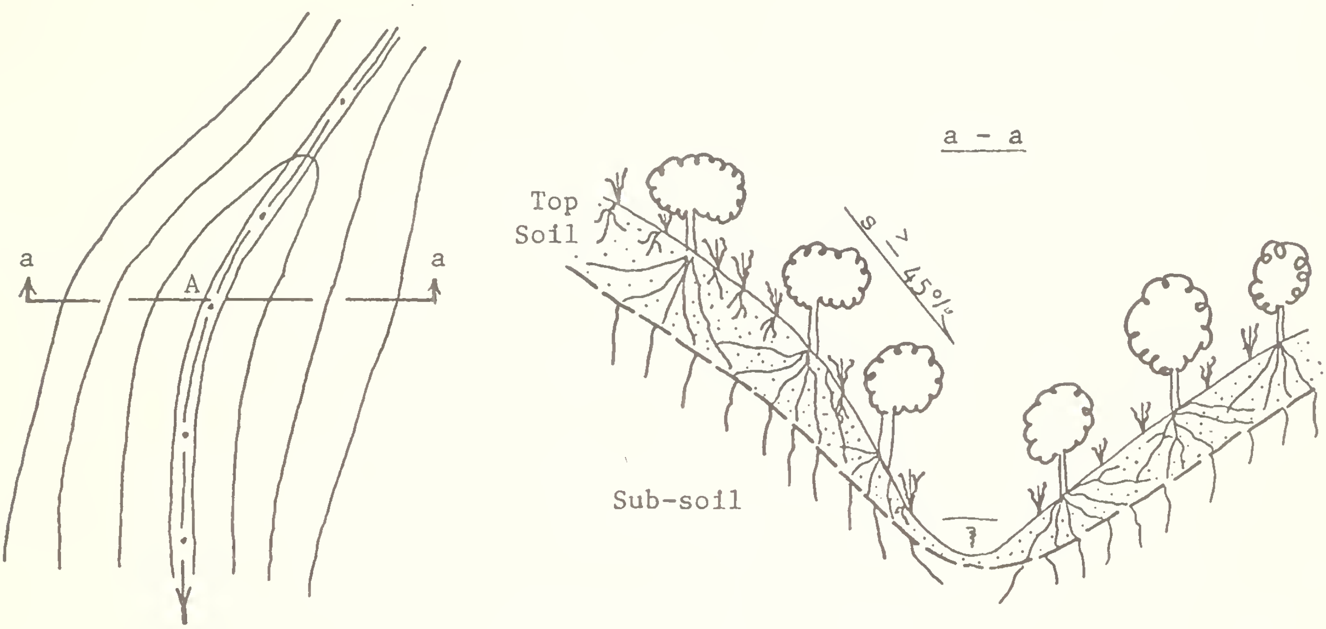
Section 3. On-Site - Long Term

Hydrology

FIGURE 2

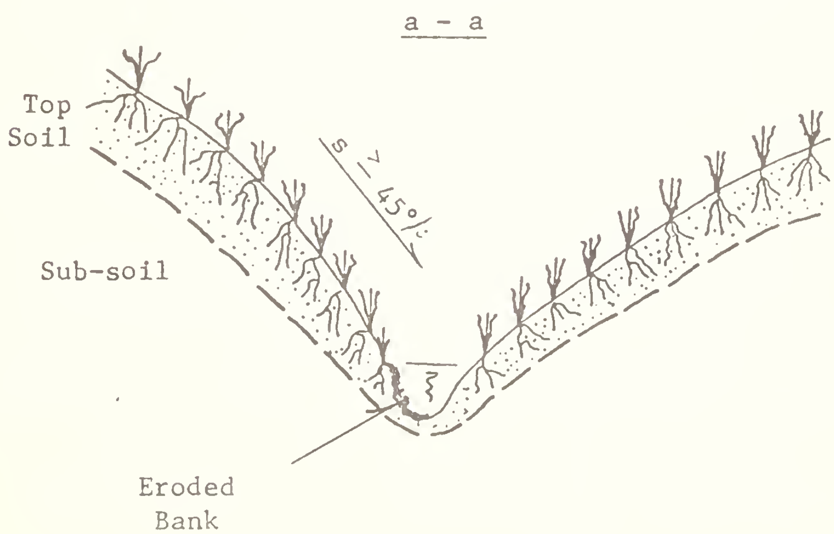
Graphical Presentation of Soil Mass Movement Genesis

1. Untreated Watershed: Stable slopes (Low channel flows, mechanical resistance to soil mass movement by tree roots).



2. Watershed converted into grassland:

Stage I. Channel scouring (Prolonged higher channel flows. Decay of tree roots left in ground. Resistance of roots weakened).



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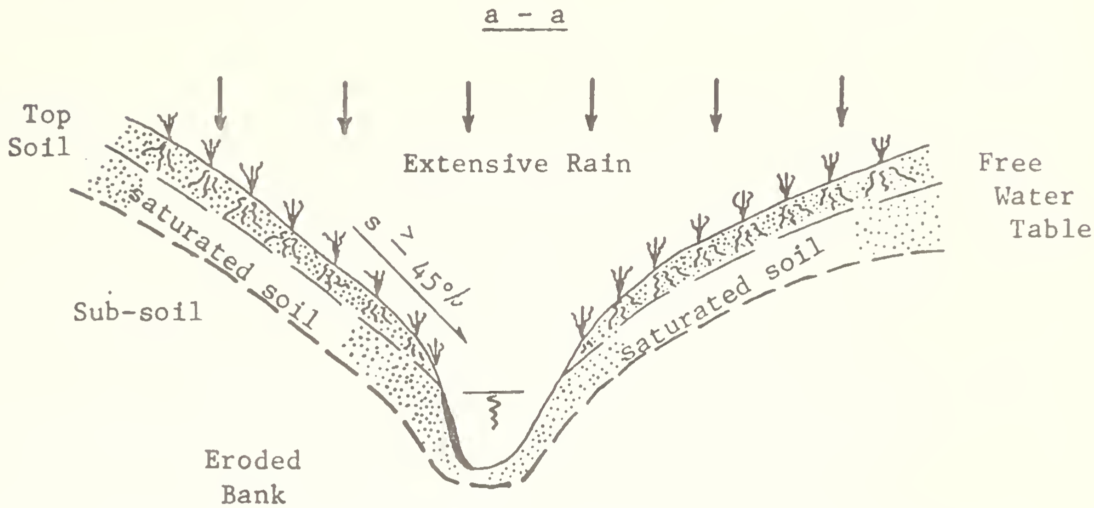
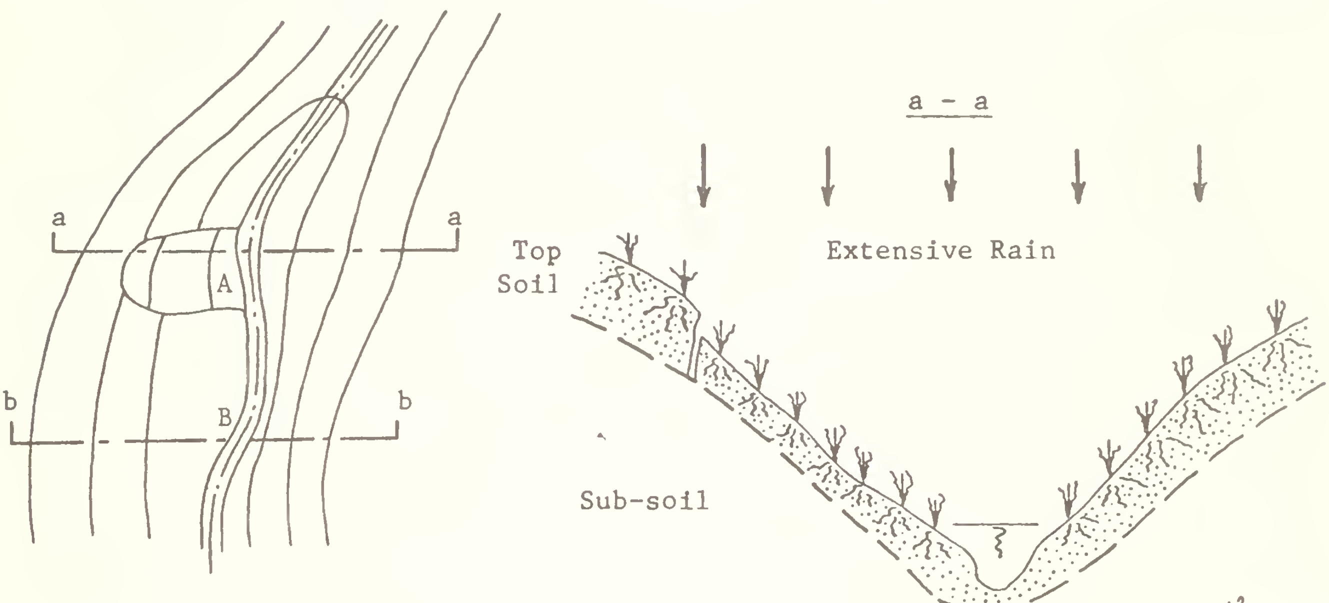
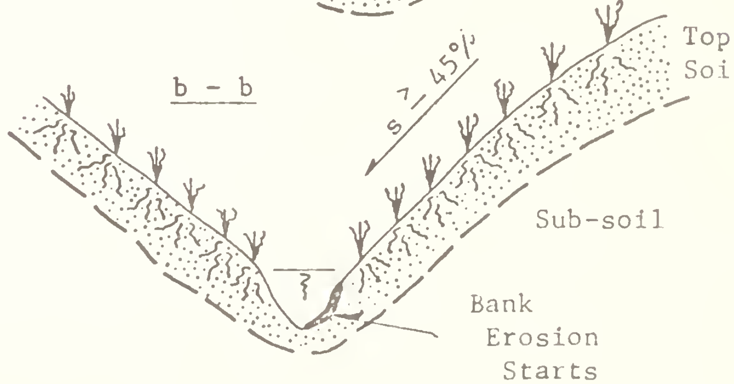
Stage II. Saturation zone in top soil (Higher and prolonged flow. Scoured bank at A. No mechanical resistance by roots. Extensive precipitation).



Stage III. Soil mass movement starts (Soil masses move into channel. Temporary storage of water upstream. Change in path of flow).



Stage IV. Favorable conditions for soil mass movement are developed at B. Stages I through III will be repeated.



humidity and perhaps increase the air temperature. These changes will be minimal since the area is strongly influenced by synoptic effects. However, microclimatic changes may take place which could be significant for small animals and plants.

Terrestrial Wildlife

The effects of conversion on wildlife can be described as a trade-off. Species which find grass cover a more ideal habitat will increase their numbers while those better adapted to brush will decrease. How the habitat changes will affect food chains and predator-prey relationships is difficult to assess. It can be assumed that a new "balance" will be established but the relative numbers in each population or what problem situations will occur during the adjustment process is unknown.

The deer population should be benefited by conversion since deer find grass more palatable than brush. However, careful planning will be required to maintain sufficient escape cover.

For most species the longer duration of flow in streams should be beneficial.

Ecology

The removal of brush and trees to prevent uptake of water from deep within the soil parent material will result in increased stream flow and is considered a beneficial effect. However, the loss of this uptake eliminates the uptake of dissolved nutrients by the deep rooted species and increases the likelihood that the nutrients will be leached into streams. This loss of nutrients can have potentially detrimental effects on the fertility level of the watershed as well as to effect downstream uses.

Recreation

-- Deer hunting should be improved by conversion by improving food supplies and the open grassland areas will make it easier for hunters to spot deer.

-- Removal of the brush should open the area up for more off-road vehicle use. Heavy use of the area could destroy grass stands. Off-road humidity and perhaps increase the air temperature. These changes will be minimal since the area is strongly influenced by synoptic effects. However, microclimatic changes may take place which could be significant for small animals and plants.

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[illegible]

[illegible]

vehicle use should be regulated during and after conversion.

-- Camping, picnicking and biking within the East Putah Creek Watershed will be affected by conversion. Whether beneficial or detrimental, the impact depends on the preferences of the individual recreationist.

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-- Camping, picnicking and hiking within the East Porah Creek Watershed will be affected by conversion. Whether beneficial or detrimental, the impact depends on the preferences of the individual recreationist.

IMPACTS

Section 4: Off-Site - Long Term

Hydrology

Sediment input from the East Putah Creek Watershed could reduce the storage capacity of downstream reservoirs.

Aquatic Life

The nutrient cycling and erosion level changes which will accompany conversion will result in increased nutrient flows in the streams and into Lake Berryessa. This enrichment may speed the aging process of the lake and may set off nuisance algal blooms.

Sediment deposition in the streams will greatly reduce potential habitat for benthic organisms. Since benthic organisms often act as a food supply for game fish, fishing potential can be decreased by stream sedimentation.

Recreation

If the quality of Lake Berryessa water is degraded, recreation of all kinds would be negatively affected. Swimming, boating, fishing, and camping are generally less pleasurable experiences in an eutrophic lake than in an oligatrophic lake (Berryess's present condition).

B. Resource Analysis Map

Considerable effort was expended on the interpretation of resource inventory maps for the preparation of use maps. These maps, consisting of a series of transparencies are presented as a single photograph. The procedure used to evaluate the watershed has been modified from the outline presented in the August 1972 progress report. The original concept of preparing 4 sets of maps, one for each of the principle uses, is still valid but involves a great deal of repetition since the same resources are being evaluated for each use. It was decided that all of the necessary information could be conveyed by providing one set of maps for the water yield. The other use maps can be derived from this one.

The water use map is a composite of 4 overlays. The vegetation overlay designates areas which are not convertible due to low densities of woody species. The two slope overlays designate areas not considered convertible (slope greater than 50%) and slopes which pose a restriction to development (slope greater than 30%). The soils map designates areas of serpentine associated soils which are considered a restriction to conversion. The combined map delineates non convertible areas in red and those with constraints for conversion in orange. The darker the orange color, the more the restriction on conversion.

These maps are useful in the evaluation of the watershed. Some of the potential uses include:

1) A synoptic view of the resources. This provides an understanding of the area which otherwise requires extensive field surveys or map interpretations.

2) A means of determining the relationships between topography, soils and vegetation.

3) For a project such as vegetation conversion, the effects of alternative management schemes can be easily discerned. For example, the alternatives of converting only areas with greater than 30° slope can be readily noted by examination of the overlays. A synoptic view of this alternative is provided and an estimate of the effects of water yield can be easily made (assuming linear relationship).

4) The areas designated as high risk areas can be made the subject of specific studies to determine how the risks can be minimized. The red tone does not indicate areas whereon conversion could not take place, but rather indicates areas where serious hazards exist that probably are not readily mitigated.

These maps present information which is easily mapable. Other information such as wildlife surveys, water quality studies, and stream flows are included in the analysis as described in the text. This information is extremely important and should not be disregarded simply because it is less adaptable to graphic presentation than the other features. Other information which is of particular interest includes the relative amounts of amendments needed for conversion within the serpentine soils; the relative sensitivity of the aquatic organisms to increased sediment loads; and the dependence of wildlife on existing vegetation for food and cover. These are the types of problems which the current research effort is attempting to deal with. As these efforts move from research toward interpretation and application it may become possible to construct interpretive maps to include such information.

The main use of these maps is to put the resource information in a form which allows an integration of information. The map thereby provides a starting point and additional information may be added as needed.

FIGURE 3. MAPPED CONSTRAINTS TO VEGETATIVE CONVERSION.

IV. Evaluation

This step involves the addition of the economic factor to the planning process, wherein values are assigned to the components of the management alternatives in conformance with present and future worth or cost. It is obvious and essential to devise the management sequences necessary for a particular alternative procedure as the watershed. Each alternative may then be assessed in part or totally as desired; or combinations of alternatives may be compared.

Needless to state, the management alternatives designed for evaluation will have incorporated the constraints and guidelines which were previously isolated for the specific site and for the program goals to be acheived.

This phase of the current program of investigation on the East Putah Creek Watershed is to at least partially be treated in ongoing work. Certain aspects will likely be determined to lie within the perview of the Department of Interior agencies who will provide the input. It is further recognized that ultimately the assessment of specific projects proposals for this planning unit will be the responsibility of the United States Department of Interior agencies involved.

V. Conceptual Plan

General Goals:

1) To enhance the productivity and use of the watershed under a program of multiple-use management.
2) To enhance and protect the environmental quality of the entire region for the enjoyment of present and future generations.

Objectives:

1) To enhance water yield from the East Putah Creek Watershed.
2) To extract all minerals from the area which have true economic value.
3) To enhance recreational opportunities of all kinds on public land within the East Putah Creek Watershed.
4) To preserve unique features for the enjoyment and education of present and future generations.
5) To maintain the water quality of Putah Creek and Lake Berryessa.

Guidelines for accomplishment of goals and objectives

Watershed

1) After a test area has been successfully converted to confirm water yield and water quality predictions, convert the watershed following these recommendations:
   a. No vegetation should be disturbed within 150 feet of a stream channel.
   b. Areas known to be unique wildlife habitats, important vegetative associations, or intensively used recreation areas should be left undisturbed.
   c. On soils where fertility is very low, conversion should not take place on slopes greater than 30%.
   d. In no case should conversion take place on slopes greater than 45%.
   e. Conversion should not take place on land where present woody vegetation provides less than 50% cover.

f. Conversion should not take place in the vicinity of natural or man-induced land slips.

g. Temporary sediment traps should be constructed when needed.

2) Do not allow water quality to be sacrificed for water yield augmentation.

Recreation

1) Develop trail systems and associated facilities for hiking and riding.
2) Manage off-road vehicle use by developing trails, camp sites, and posting boundaries.
3) Improve access and consolidate the public land to facilitate hunting and fishing.
4) Develop vegetative interpretive trails in the areas where rare and unique plant associations are found.
5) Regulate hunting activity whenever possible to maintain healthy wildlife populations.
6) Improve access to public lands adjacent to Putah Creek and Lake Berryessa.
7) Establish regular patrols of the East Putah Creek Watershed for public safety and law-enforcement purposes.

Mining

1) The area will remain open to mineral exploration, development and extraction.
2) Prohibit mining activity whcih degrades water quality or interferes with recreational activity on public lands.

Grazing

1) Grazing on converted land should be carefully controlled to prevent overgrazing.
2) On public land the interests of ranchers should not supercede those of the general public. In most cases where conflicts result the public's interest should prevail.

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SECTION II

AGRONOMIC STUDIES

AGRONOMIC STUDIES ON THE HENNEKE SOILS OF THE EAST PUTAH CREEK WATERSHED, 1972-73

Milton B. Jones

INTRODUCTION

The agronomic work for the 1972-73 year covers four main areas: 1) Residual effects of fertilizers. These studies are of major importance for economic information. If fertilizers last a long time the cost can be spread over a period of years. However, those fertilizers which leach out rapidly not only are uneconomical but also tend to pollute streams and lakes; 2) Diagnostic methods for soils and plants. Chemical tests on soils and plant tissue are being correlated with plant growth for diagnostic purposes. Since nitrogen, phosphorus and sulfur were deficient on all soils tested and calcium was deficient on only part of them, it is important from the standpoint of economics to know if calcium is needed and how much should be applied. On some of the watershed sites herbaceous plants simply will not survive without the addition of calcium, while other locations require no additional calcium. Potassium and molybdenum were deficient on some sites but these elements did not make the difference between success and failure; 3) Variety testing. If grasses and clovers are to replace the brush species now in the watershed it is important to have those that are well adapted to the area. For this reason variety trials have been established in the field and in the greenhouse on Henneke soil to find varieties that will be best adapted to the Henneke soil environment; 4) Brush manipulation and field seeding studies.

In the fall of 1972, 30 acres of brush in Jerusalem Valley were cleared and seeded to grasses and legumes. In spite of certain difficulties it was the most successful seeding of an unfenced area to date.

Details of procedures followed in many of these experiments have been given in previous years and will not be repeated in this report except where it is necessary to make it understandable to the reader. If more details are required consult reports for the two preceding years.

RESULTS

Residual Value of Fertilizers

Table 1 gives the 1973 forage yields, percentage clover and yield of clover from the Red Elephant Mine experiment. Original treatments were applied in October 1970 and some were reapplied in October 1972. There was no increase due to nitrogen applied in 1970 reflected in 1973 yields of forage; however, the percentage of clover was reduced by application of N three years previously and N applied at the beginning of the current growing season practically eliminated clover from the stand. Highest grass yields were achieved where the current application of N was applied. Phosphorus needs had been satisfied from the previous application. The residual effect of P was excellent, in fact, on the average, reapplication of P did not significantly improve yields over P that had been applied in 1970. Potassium, sulfur and calcium were not so low as to make the difference between success and failure on this site and the variation was such that differences due to these treatments were not significantly different at the 5% level.

Based upon these and other studies in the north coast region, a heavy dose of P is required for establishment of grasses and legumes and

this P should last for a number of years. The use of N should be avoided because it reduces the stand of legumes and symbiotic N fixation and leaches into the groundwater and reservoir. Other studies show that symbiotically fixed N does not contribute to groundwater N.

Diagnostic Methods for Soils and Plants

In the 1972 report, the yields of subclover as affected by application of fertilizers were given for exploratory experiments in the greenhouse on 23 Henneke soils taken from the watershed. During the 1972-73 year chemical determinations have been made on these samples. Protein concentrations were determined in the clover to measure symbiotic nitrogen fixation and to obtain a better indication of any deficiency in molybdenum. In 19 of 23 soils, applied molybdenum increased the protein values in the clover. Molybdenum increased clover yields on two more soils. The two remaining soils not responding to molybdenum in any way were so deficient in calcium that responses to other deficient elements could not be obtained. It appears very likely that at least 90% of the soils were molybdenum deficient.

The concentration of calcium in subclover tops from 23 soils is reported in Table 2. The values varied widely from soil to soil but the average where no calcium was applied was about 0.5%. The application of Ca increased the average Ca level in the clover to 1.2%. The percent Ca in unfertilized subclover tops plotted against relative yields of clover fertilized with P, K and S gave a critical value of about 0.55% Ca (Fig. 1).

The relationship between exchangeable Ca in the soil and the relative yield of clover when P, K and S were applied is given in Figure 2. About 4.5 meq exchangeable Ca/100 g soil is the critical level.

The concentration of magnesium in the subclover is given in Table 3. The magnesium values increased with the application of P, K and S and adding Ca increased the magnesium level even more, on the average. There did not appear to be any significant relationship between relative clover yields and levels of magnesium in the subclover. There was a relationship, however, between relative yields of clover without Ca fertilization and the Ca/Mg ratio as given in Figure 3. However, using the Ca/Mg ratio as the criteria for clover growth did not appear to have any advantage over simply using percentage of Ca. The critical Ca/Mg ratio appeared to be about 0.50.

Subclover and soft chess have been grown on soil No. 6 which was lowest in exchangeable Ca. Increasing levels of Ca were applied. Figure 4 shows the relationship between the percentage of Ca in the subclover and soft chess and their yield. The point at which subclover became deficient in Ca was about 0.70% Ca, 0.15% higher than the value obtained in Figure 1. The values from soft chess were very low in comparison to subclover, ranging from less than 0.1% to about 0.2% Ca. These values indicate that the critical Ca level for soft chess is about 0.2%, much lower than for subclover. Figure 5 shows the relationship between exchangeable Ca and yield of the two species. The critical level appears to be about 6.0 meq Ca/100 g of soil or 1.5 meq higher than the values obtained when exchangeable Ca of all soils were plotted in Figure 2.

The effect of stage of plant maturity, plant parts and other factors that might be influencing the Ca uptake or critical level needs some study. One experiment was carried out to obtain these levels during this 1972-73 year. A Henneke soil extremely low in Ca was used, but it required much less Ca to satisfy the demands of the plant than did

The concentration of magnesium in the subclover is given in [illegible]. The magnesium values increased with the application of P, K and N and adding Ca increased the magnesium level even more, on the average. There did not appear to be any significant relationship between relative [illegible] and levels of magnesium in the subclover. There was [illegible], however, between relative yields of clover [illegible] the [illegible] shown in Figure [illegible]. However, [illegible] growth did not [illegible] magnesium [illegible]. The [illegible]

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soil No. 6 as illustrated in these figures. This experiment is not yet completed.

While we can detect Ca deficiency by soil and plant analysis, detailed experiments on a number of soils will be required to determine just how much Ca should be applied in each instance to satisfy the Ca needs for grass and clover plants to be established on these soils.

At each of the 23 sites that had been previously sampled and tested in the laboratory and greenhouse the brush was cleared away in an area 15 by 10 feet. This area was sown to a mixture of Hykon rose clover, Geraldton subclover and soft chess at a seeding rate of 100 lbs/acre with 1/3 of each variety making up the mix; the seed was raked into the soil. One plot, 4 by 4 feet, was left unfertilized, a second plot was fertilized with P and S, and a third was fertilized with P, S and Ca. These three treatments were covered with barley straw at the rate of 1 ton/acre and 1/2" diameter wire mesh cages were placed over each of the three treatments to protect them from bird and rodent damage. The purpose of this study was to determine if Ca, P and S responses could be seen in the field since we had already measured them in the greenhouse. Since there was only one replication at each site the results were considered observational. In general, they agree with our laboratory and greenhouse results, at least 2/3 of the sites responded to Ca and virtually all responded to P and S. We suffered some bird or rodent damage in some spots and erosion or other damage to some cages and thus some results were lost.

Table 5 gives the yield of subclover growing on soils from three additional sites from the East Putah Creek watershed and treated as indicated. Site 22a was extremely deficient in Ca and clover growth on soil from site 24 appeared to be slightly depressed where Ca was applied.

Aerial photographs of these and other sites in the study area indicate differences in color going from Ca deficient to Ca sufficient sites. It appears worthwhile to follow this observation with analytical work on samples taken from a number of sites to see if aerial photos can be used to diagnose calcium deficient areas.

Variety Testing

A number of species and varieties of forage legumes have been tested in the field and their productivity and capacity to survive under these difficult environments have been observed. Some varieties of rose clover (*Trifolium hirdum*) have reproduced themselves and have grown well the third year after seeding; the variety Hykon appears to be one of the best. Geraldton subclover (*T. subterraneum*) has also produced seed, fixed N, and produced good forage. The medics and vetches do not appear to be doing well at this time. A range of tolerances to low Ca and high magnesium has been observed in some legumes with Hykon rose clover being particularly outstanding. Since the addition of Ca in the field in heavy amounts could be very expensive, this could be an important observation.

Brush Manipulation and Seeding

At the Red Elephant Mine site, part of which was cleared in 1970 and the rest in 1971, sprouting scrub oak, manzanita, and chamise were sprayed with 2,4-D in June of 1970 using backpumps. This treatment proved to be very effective in killing the resprouting brush on the cleared area.

At the Jerusalem Valley site an anchor chain on which short rails had been welded (designed by William Lamb) was used to knock down the brush on 30 acres in November 1972. The chain was pulled over 10 acres per hour with two tractors. The area was chained twice and seeded with

Aerial photographs of these and other sites in the study area indicate differences in color going from Ca deficient to Ca sufficient sites. It appears worthwhile to follow this observation with a statistical study on samples taken from a number of sites to see if aerial photographs can be used to diagnose calcium deficient areas.

Variety Testing

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a mixture of clovers and grasses, then the chain was pulled over the area a third time, mainly for the purpose of working the seed into the soil. Alternate strips of ammonium phosphate (16-20-0) at the rate of 300 lbs/acre, singlesuperphosphate (SSP) at 500 lbs/acre, and the check were made across the 30-acre area.

The seeding mixture on a per-acre basis consisted of 2 lbs. Hykon rose clover, 2 lbs. Geraldton subclover, 2 lbs. Jemalong medic, 2 lbs. woolypod vetch, 1.5 lbs. Hardinggrass, 1.5 lbs. Palestine orchardgrass, and 3 lbs. soft chess. This seed was purchased from Northrup-King and Co. in Yuba City, Ca. It was requested that the legume seed be inoculated with "WR" inoculum by the seed pellet inoculation method.

Table 6 shows the percentage of square-foot frames in which various species occurred in each of the treatments; it also shows plant heights. It is evident that both grasses and legumes occurred more frequently and grew more vigorously where 16-20-0 was applied than in the check or SSP treatments. Nodules could not be found on any of the legumes in any of the treatments. A legumes variety trial was established on an unfertilized check. These legumes were not fertilized with N but were fertilized with P and S; the legumes were inoculated at Davis with WR strain of bacteria. The variety trial showed vigorous growth of legumes and large, healthy nodules on all legumes which were dug up. It was concluded that legumes seeded on the 30 acres of cleared land were not properly inoculated. It could be argued that the 4-week delay from time of inoculation until seeding was too much and that the bacteria died. However, our experience indicates that many of the bacteria would live for longer periods than this and that some of the legumes would have nodules on them. To have no indication of N fixation or nodulation on the legumes indicates that the proper a mixture of clovers and grasses, then the chain was rolled over the area a third time, mainly for the purpose of working the seed into the soil. Alternate strips of ammonium phosphate (16-20-0) at the rate of 300 lbs/acre, triplesuperphosphate (TSP) at 300 lbs/acre, and the check were made across the 30-acre area.

The seeding mixture on [illegible] has [illegible] [illegible] lbs/acre [illegible] clover, [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible], [illegible] [illegible] [illegible], [illegible] [illegible] soft chess. This seed was purchased [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] by the seed [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] each of the [illegible] [illegible] [illegible] [illegible] grasses and legumes occurred [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] bacteria were not there in the first place. This is an extremely important point in successful establishment of these legumes and great care should be taken to see that proper inoculation has been carried out before seed is placed in the ground.

The chaining of the brush worked well and the resprouting brush were sprayed with 2-4-D in May of 1973 to make conversion permanent.

Table 7 gives cost estimates for the various treatments on the 30-acre conversion plot. The SSP costs $60/ton and was applied at 500 lbs/acre, giving a $15/acre cost while the ammonium phosphate was $85/ton and was applied at 300/lbs/acre rate. Since the ammonium phosphate is more costly and N is rather temporary in its effect compared to the phosphorus, the SSP treatment will be more economical in the long run. Both fertilizers have the same amount of P in them. On a large non-experimental conversion area we would probably not recommend such a complex mixture of species and this would reduce the cost somewhat. Cost of conversion will vary not only with prices of the various materials and labor but also with the program that is decided upon for each area to be converted which will depend on terrain, soil, density and type of brush, and the requirement of fertilizer.

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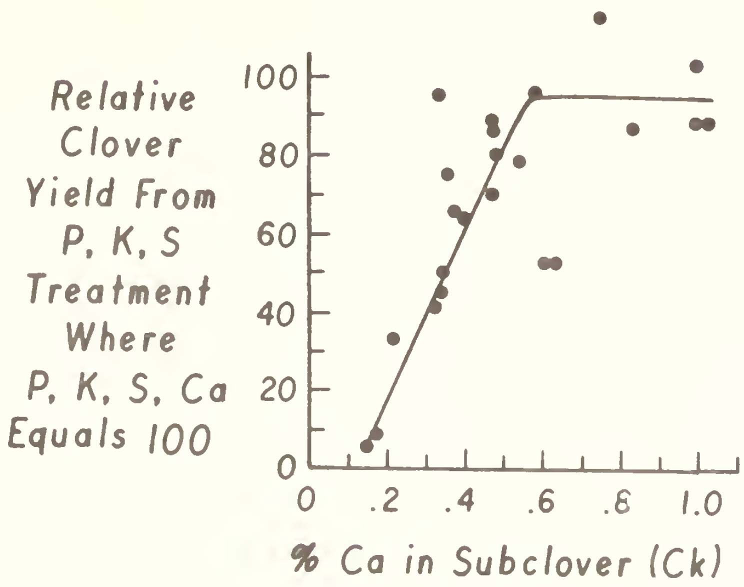
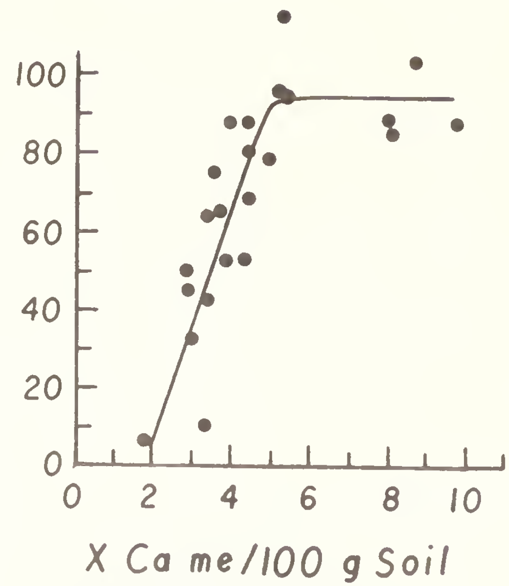
Figure 1



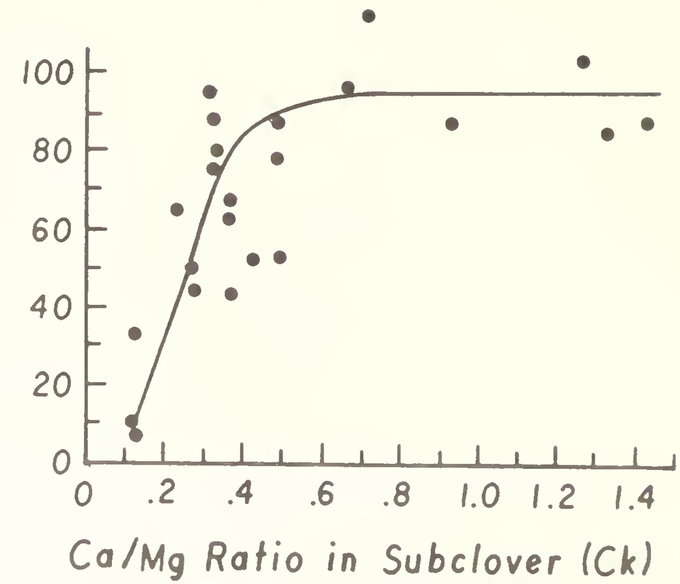
Relative yields of subclover fertilized with P, K and S, but not fertilized with Ca in relation to percentage of Ca in the subclover tops from 23 Henneke soils. The P, K, S and Ca treatment on each soil was divided into the P, K, S treatment to obtain the relative value.

Figure 2



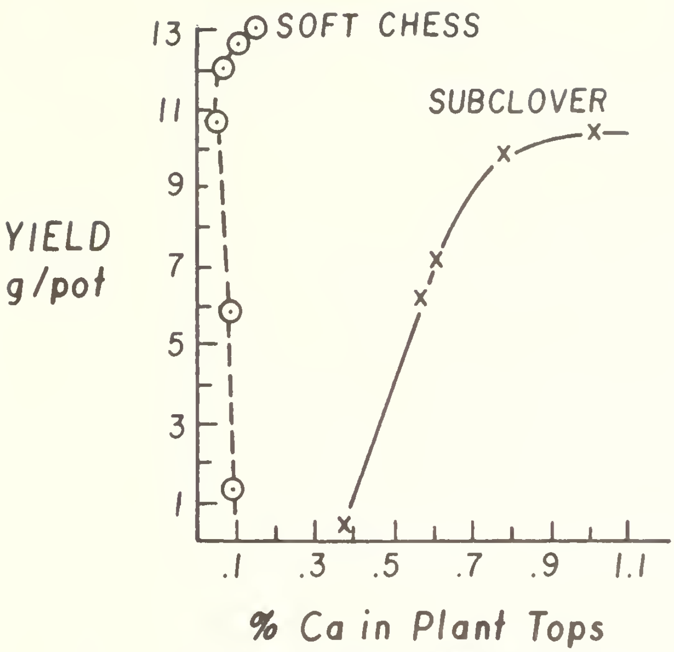
Relative yields of subclover fertilized with P, K and S but not with Ca in relation to exchangeable soil Ca.

Figure 3



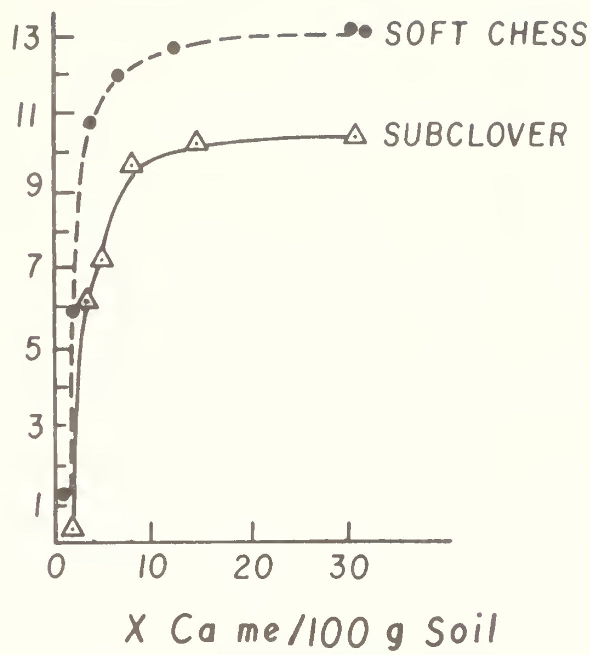
Relative yields of subclover fertilized with P, K and S but not with Ca in relation to Ca/Mg ratios.

Figure 4



Effect of increasing Ca applications on yield and Ca percentages in subclover and soft chess growing on soil #6.

Figure 5



Effect of increasing Ca applications on yield of subclover and soft chess as related to exchangeable Ca on soil #6.

Table 1. Yield of forage clipped April 11, 1973 from the Red Elephant Mine plots as affected by various fertilizers applied in October 1970 and October 1972.

	Fertilizer treatments		Yield of forage	Percentage	Yield of clover
	October 1970	October 1972	lb/A	clover	lb/A
1.	Complete*		1840	18	331
2.	-N		2304	53	1221
3.	-P		752	3	23
4.	-K		2216	10	222
5.	-S		2024	23	466
6.	-Ca		1680	30	504
7.	-K, -P		504	3	15
8.	-N, -K		2112	30	634
9.	-N, -S		1848	60	1109
10.	-N -micronutrients	+N	4456	1	45
11.	-N, -B	+P	2712	50	1356
12.	-N, -Ca	+S	2024	73	1478
13.	-N, -Mo	+NP	4736	1	47
14.	-N, -Zn	+NS	4640	2	93
15.	-N, $+Ca_{650}$	+PS	1960	58	1137
16.	-N, $+K_2$	+NPS	4936	1	49
17.	Check		720	6	43
	L.S.D. (.05)		920	17	496

* The complete treatment consisted of 100 lb/A N, P and K, 130 lb/A S, 65 lb/A Ca, 5 lb/A B, Cu and Zn, and 1/4 lb/A Mo. These elements were omitted from the several treatments in 1970 as indicated. In 1972 additions of 100 lb/A N, and P and 130 lb S/A were applied as indicated.

Table 2. Percent Ca in subclover as affected by fertilization of 23 Henneke soils.

	1	2	3	4	5	6	7	8	9	10	11	12
1. Ck.	.60	.46	.43	.36	.46	.14	.39	.35	.17	.21	.98	.57
2. Comp.	.48	.52	.53	.42	.46	.25	.42	.45	.24	.32	1.09	.63
3. +N	.54	.39	.42	.30	.40	.14	.38	.35	.18	.24	.93	.50
4. +Ca	1.60	1.14	1.15	1.12	1.27	1.46	1.18	1.06	1.10	1.24	1.50	1.14
5. +Mo	.50	.44	.39	.38	.40	.12	.36	.31	.19	.25	.81	.47
6. -P												
7. -S												
8. -K	.43	.39	.36	.26	.40	tr.	.32	.30	.18	.17	.86	.60
L.S.D. (.05)	.24	.10	.08	.05	.14	.13	.09	.10	.06	.13	.07	.07

	13	14	15	16	17	18	19	20	21	22	23	$\bar{x}$
1. Ck.		.46	.53	.83	.63	1.08	.74	.46	.40	.97	.36	.53
2. Comp.	.35	.54	.58	.93	.62	1.00	.71	.50	.45	.98	.37	.56
3. +N	.30	.42	.45	.77	.52	.98	.69	.42	.39	.84	.39	.48
4. +Ca	1.14	.99	1.09	1.12	1.32	1.74	1.40	1.32	1.16	1.75	1.22	1.32
5. +Mo	.28	.41	.45	.74	.49	.90	.64	.42	.42	.83	.38	.46
6. -P											.37	
7. -S											.36	
8. -K	.24	.43	.45	.81	.52	1.20	.70	.42	.38	.94	.36	.49
L.S.D. (.05)	.06	.06	.07	.08	.09	.22	.06	.09	.04	.11	.10	.02

Table 3. Percent Mg in subclover as affected by fertilization of 23 Henneke soils

	1	2	3	4	5	6	7	8	9	10	11	12
1. Ck	1.22	.94	1.33	1.52	1.44	1.15	1.48	1.08	1.48	1.51	.74	.86
2. Com.	1.76	1.46	1.59	1.80	1.36	1.56	1.56	1.57	1.53	1.71	.98	1.18
3. +N	1.50	.96	.84	1.20	1.02	1.66	1.25	1.28	1.50	1.45	.87	1.01
4. +Ca	1.66	2.04	2.08	2.15	2.23	1.91	1.89	2.08	1.72	1.95	1.45	1.57
5. +Mo	1.09	1.02	1.04	1.42	1.02	1.62	1.12	1.17	1.55	1.42	.63	0.93
6. -P												
7. -S												
8. -K	1.59	1.25	1.40	1.70	1.49	--	1.42	1.46	1.44	1.78	1.02	1.31
L.S.D. (.05)	.17	.20	.24	.20	.30	.18	.15	.22	.18	.29	.20	.19

	13	14	15	16	17	18	19	20	21	22	23	$\bar{x}$
1. Ck		1.38	1.07	.89	1.42	.71	1.06	1.24	1.08	.78	.98	1.15
2. Comp.	1.60	1.33	1.19	1.19	1.38	.87	1.00	1.25	1.10	.80	1.29	1.35
3. +N	1.05	1.05	1.05	1.06	1.17	.78	1.08	1.08	1.03	.68	1.30	1.12
4. +Ca	1.82	1.61	1.65	1.32	1.72	1.32	1.40	1.42	1.34	1.28	1.48	1.70
5. +Mo	1.20	.98	.88	.78	1.09	.71	.96	1.10	1.05	.79	1.25	1.08
6.											1.27	
7.											1.30	
8.	1.88	1.61	1.34	1.14	1.50	.94	1.30	1.54	1.39	.87	1.29	1.39
L.S.D. (.05)	.22	.23	.18	.15	.16	.13	.17	.25	.18	.11	.15	.04

Table 4. Ca/Mg ratios in subclover tops as affected by fertilization of 23 Henneke soils.

	1	2	3	4	5	6	7	8	9	10	11	12
1. Ck	.49	.49	.32	.24	.32	.12	.26	.32	.11	.14	1.32	.66
2. Comp.	.27	.36	.33	.23	.34	.16	.27	.29	.16	.19	1.11	.53
3. +N	.36	.41	.50	.25	.39	.08	.30	.27	.12	.17	1.07	.50
4. +Ca	.96	.56	.55	.52	.57	.76	.62	.51	.64	.64	1.03	.73
5. +Mo	.46	.44	.38	.27	.39	.07	.32	.26	.12	.18	1.29	.51
6. -P												
7. -S												
8. -K	.27	.31	.26	.15	.27	--	.23	.21	.12	.10	.84	.46

	13	14	15	16	17	18	19	20	21	22	23
1. Ck		.33	.50	.93	.44	1.52	.70	.37	.37	1.24	.37
2. Comp.	.22	.41	.49	.78	.45	1.15	.71	.40	.41	1.22	.29
3. +N	.29	.40	.43	.73	.44	1.26	.64	.39	.38	1.24	.30
4. +Ca	.63	.61	.66	.85	.77	1.32	1.00	.93	.87	1.37	.82
5. +Mo	.23	.42	.51	.95	.45	1.27	.67	.38	.40	1.05	.30
6. -P											.29
7. -S											.28
8. -K	.13	.26	.34	.71	.35	1.28	.54	.27	.27	1.08	.28

Table 5. Yield of subclover from 3 Henneke soils as affected by fertilization.

Treatment	Soil Site Designation		
	3a	22a	24
	------------g/pot------------		
1. Complete	3.1b	*	8.6c
2. +N	5.3d	0.4a	10.4d
3. +Mo	4.5c	*	13.1e
4. +Ca	4.9cd	6.3b	6.0b
5. -P	1.0a	*	1.1a
6. -K	1.0a	*	5.4b
7. -S	1.0a	*	0.8a
8. Ck (no fert.)	0.5a	*	0.7a
L.S.D. (.05)	0.5		0.6

Means followed by the same letter are not significantly different from each other.

* Plants did not survive beyond the first true leaf stage.

Table 6. Percentage of square foot frames in which various seeded species or bare ground occurs as affected by fertilizer treatments. Counts were made April 19, 1973 in 85 squares per treatment at the Jerusalem Valley site.

	Ck	SSP	16-20	L.S.D. (0.05)
	percent			
Bare ground only	36	24	4	15
Rose clover	14	20	48	15
Subclover	1	0	2	N.S.
Vetch	16	17	22	N.S.
Mean for legumes	10	12	24	7
Soft chess	54	52	70	N.S.
Palestine orchard	12	10	20	N.S.
Hardinggrass	2	5	8	N.S.
Mean for grasses	23	22	33	10
Chamise	26	30	25	N.S.

Estimated plant heights as affected by fertilization.

	Ck	SSP	16-20
	inches		
Rose clover	2	3	10
Vetch	3	3	12
Soft chess	5	5	10
Orchard	4	4	10

The large clover plants in the 16-20-0 treatment had no nodules on their roots and clover in the checks and single superphosphate treatments appeared nitrogen deficient. On the same site, clover in a variety trial fertilized only with phosphorus and sulfur was healthy and had large nodules. We concluded that seed used on the 30 acres had not been properly inoculated.

From the variety trial it appears that properly inoculated clover will grow well in the area without the use of applied nitrogen.

Table 7. Cost per acre of the three treatments used on 30 acre conversion study in Jerusalem Valley.

	Check	Ammonium phosphate	Single-superphosphate
1. Chaining of brush	$ 5.70	$ 5.70	$ 5.70
2. Seed (Oct. 1972 prices)	11.86	11.86	11.86
3. Fertilizer	---	12.75	15.00
4. 2,4-D spray @ 1 gal/A plus application	10.00	10.00	10.00
TOTAL	$27.56	$40.31	$42.56

These costs do not include the labor of spreading seed and fertilizer, and ferry time on tractors and other equipment.

SECTION III

HYDROBIOLOGICAL STUDIES

Hydrobiological Studies on East Putah Creek Watershed

Allen W. Knight and Clifford A. Siegfried

Hydrobiological investigations during the past year have concentrated upon the interaction between substrate type and benthic productivity. Projects proposed for the East Putah Creek Watershed may introduce increased loads of fine sediment into the streams of the watershed. The deposition of this fine particulate matter may seriously reduce the productivity of the streams present in the watershed (Knight and Siegfried, 1972). Studies in other regions have shown reductions in benthic productivity in streams affected by the introduction of fine sediment. (Cairns, 1968; Clifford, 1966; Cordone and Pennoyer, 1960; Gammon, 1970; King and Ball, 1964, 1967; Tebo, 1955). Field and laboratory studies now in progress have been designed to provide information for the quantitative assessment of the possible impact of increased sediment loads in the streams of the East Putah Creek Watershed.

Field investigations were originally planned to incorporate the use of basket samplers filled with various substrate types and various concentrations of fine sediments. Analysis of colonization rates, standing crops and community diversity of benthic communities colonizing each substrate type would provide an indication as to the effect of substrate alteration upon benthic communities. Attempts to install these substrate baskets within Eticuera and Hunting Creeks were unsuccessful due to the proximity of bedrock and compacted materials to the substrate surfaces. It was therefore decided that the best alternative approach for investigating the relationship between substrate type and benthic productivity would involve quantitative analysis of substrates coupled with studies on benthic productivity. Comparison of benthic productivity between selected sites within a stream and between different streams generally reflects differences in substrate type. The relationship between benthic productivity and substrate type should provide a basis for the prediction of the effects of substrate alteration within the streams of the East Putah Creek Watershed.

Hydrobiological Studies on East Putah Creek Watershed

Allen W. Knight and Clifford A. Siegfried

Hydrobiological investigations during the past year have concentrated upon the interaction between substrate type and [illegible] [illegible] projects proposed for the East Putah Creek watershed [illegible] introduce increased loads of fine sediment into the streams [illegible] [illegible]. The deposition of this fine particulate [illegible] [illegible] the productivity of the streams presently [illegible] and Siegfried, 1972). Studies in other [illegible] [illegible] productivity in streams after [illegible] [illegible] sediment. (Cordone, 1956; Chutter, [illegible] [illegible] [illegible] [illegible], 1971; [illegible] and Bell, 1966; [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

[illegible]

Substrate and benthic samples are collected simultaneously by means of a sampling device that delineates $0.0314 m^2$ of bottom area. All substrate particles and benthic forms within this area are collected and preserved in the field. At the laboratory all organisms are removed from the substrate samples and the substrate and benthic samples are then analyzed separately. Benthic forms are identified and measured to the nearest millimeter for later estimates of benthic production (Hamilton, 1969; Hynes and Coleman, 1968). Substrate analysis involves several steps:

1. Separation into two fractions, one for size analysis and one for analysis of organic content.
2. Oxidation to remove organics from size fraction.
3. Separation of fine sediment by wet sieving.
4. Drying of coarse sediment.
5. Separation of coarse substrate into different size ranges by dry sieving.
6. Pipet analysis of fine sediment to determine percentage of silts and clays.
7. Weighing of the different size fractions.
8. Organic content analysis.

Preliminary results support the conclusion that, as fine sediment becomes an increasingly large component of the substrate, benthic diversity declines. Average diversity values[1] for stations within Eticuera Creek, when arranged in order of decreasing value, reflect the amounts of fine sediment present at each station. Highest diversity occurs at those stations with the least proportion of fine sediment and lowest diversity occurs at stations with the largest proportion of fine sediments. Diversity values from the other streams of the watershed also reflect this relationship. After sufficient data is collected and analyzed, it should be possible to predict which streams or section of stream are most susceptible to damage from increased sediment loads.

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[1]diversity index used: $H = -\sum(\frac{n_i}{N}) \log (\frac{n_i}{N})$, where n_i = number of individuals of species i, N = total number of individuals in sample).

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1. Separation into two fractions, [illegible] and analysis of organic content
2. [illegible] organic [illegible]
3. [illegible]
4. [illegible]
5. [illegible]
6. [illegible]
7. [illegible]
8. [illegible]
9. [illegible]

Laboratory investigations were undertaken during the past year to study the effects of substrate alteration and suspended sediment upon aquatic macrobenthos. The principle test organism has been a large, carnivorous stonefly, Acroneuria californica. This stonefly occurs in Putah Creek and is common throughout Northern California. The presence of this stonefly in a stream is often used as an indicator of "clean water". As a "clean water" indicator, A. californica's reactions to sedimentation can be generalized to indicate the probable reactions of the entire clean water fauna.

One series of studies was designed to measure changes in drift, the passive transport of macrobenthos via water currents, induced by sedimentation. Gammon (1970) linked increases in drift rates to increases in suspended sediment concentrations, indicating that increased drift can be used as an indicator of stress in aquatic organisms. Our studies made use of eight laboratory streams, each supplied with rubble and coarse gravel substrates and stocked with A. californica. Drift was measured by placing nets at the downstream end of each laboratory stream in order to capture all drifting organisms. After measurements to establish normal drift rates, four streams were exposed to sedimentation. Subsequent drift in the streams exposed to sedimentation was consistently two to three times higher than that in the clear streams. Additional observations during the course of the study support the conclusion that the higher drift rates reflected stress in those organisms exposed to sedimentation. A. californica showed a strong avoidance reaction to sediments. Many nymphs went as far as to crawl out of the water in their attempts to avoid exposure to fine sediment. Recovery of A. californica nymphs from the clear streams, after termination of the study, was 100%, while recovery in the sedimented streams was 67%, reflecting losses as a result of avoidance and death.

Another series of drift studies were conducted to study the reactions, in terms of drift rates, of A. californica and Pteronarcys princeps to various substitute types. P. princeps is another large stonefly found in Putah Creek, and like A. californica prefers coarse, clean substrate. Results from these studies showed drift to be lowest on "normal" cobble and gravel substrates and increase as the proportion of

fine substrate particles increased. This increase in drift can be interpreted as a manifestation of stress induced by unfavorable substrates. Stress in aquatic organisms will also be reflected in lower growth rates, survival and reproductive success.

The results of our studies indicate that fine sediment can pose a serious threat to benthic communities and should be considered in the impact assessment of land management practices. The integration of results from field and laboratory studies should provide a predictive basis for the assessment of possible effects of land management practices on the streams of the East Putah Creek Watershed.

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